Design of Sedimentation Basins

Prof. Dr. Jabbar H. Al-Baidhani

Design of Sedimentation Basins

Sedimentation basins , as noted, will always have a detention time somewhat less than the nominal value and a surface overflow rate somewhat higher than nominal as a result of nonideality of the of the flow pattern. Design of sedimentation basins is directed toward reducing the degree of nonideality.

Design of Sedimentation Basins

Sedimentation tanks may be rectangular or square. In rectangular basins, the is directed along the long axis. This flow pattern minimizes the effect of inlet and outlet disturbances

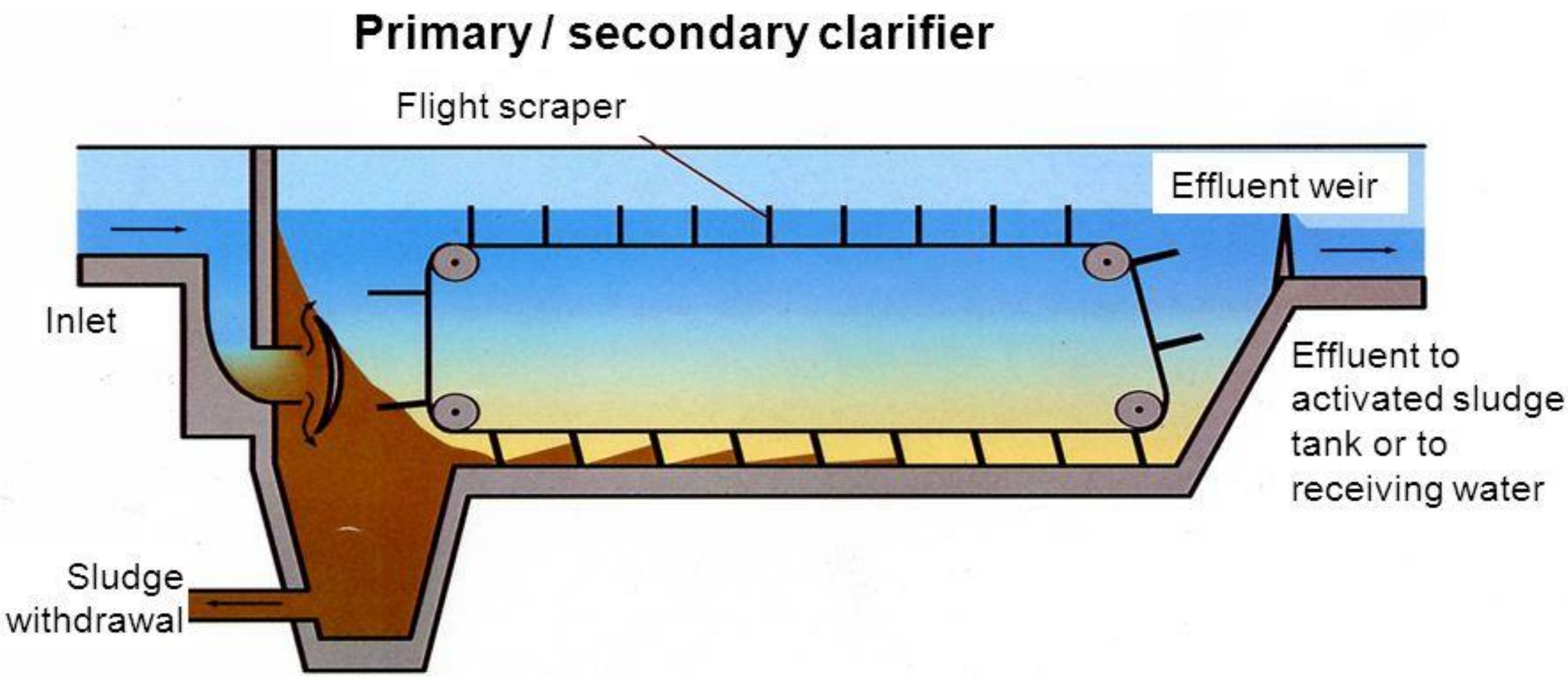
Design of Sedimentation Basins

Sludge removal equipment in such basins consists of horizontal scrapers which drag the solids to the hopper at one end, from which they are removed intermittently or continuously by gravity or augers. Typical designs are shown in Figures below. Vacuum or siphon devices may be used to remove sludge from clarifiers, but such devices are best suited for very light flocculent sludges such as those encountered in biological wastewater treatment processes.

Design of Sedimentation Basins

. Rectangular basins offer certain economies in construction if common wall design is used. Square basins are occasionally used for clarifiers. Their flow pattern is not as desirable as that in rectangular designs, and the sludge removal equipment is more complicated. Square basins generally employ rotating scrapers similar to those in circular clarifiers with an additional corner sweep mechanisms similar to that shown in figure below.

Rectangular sedimentation tank



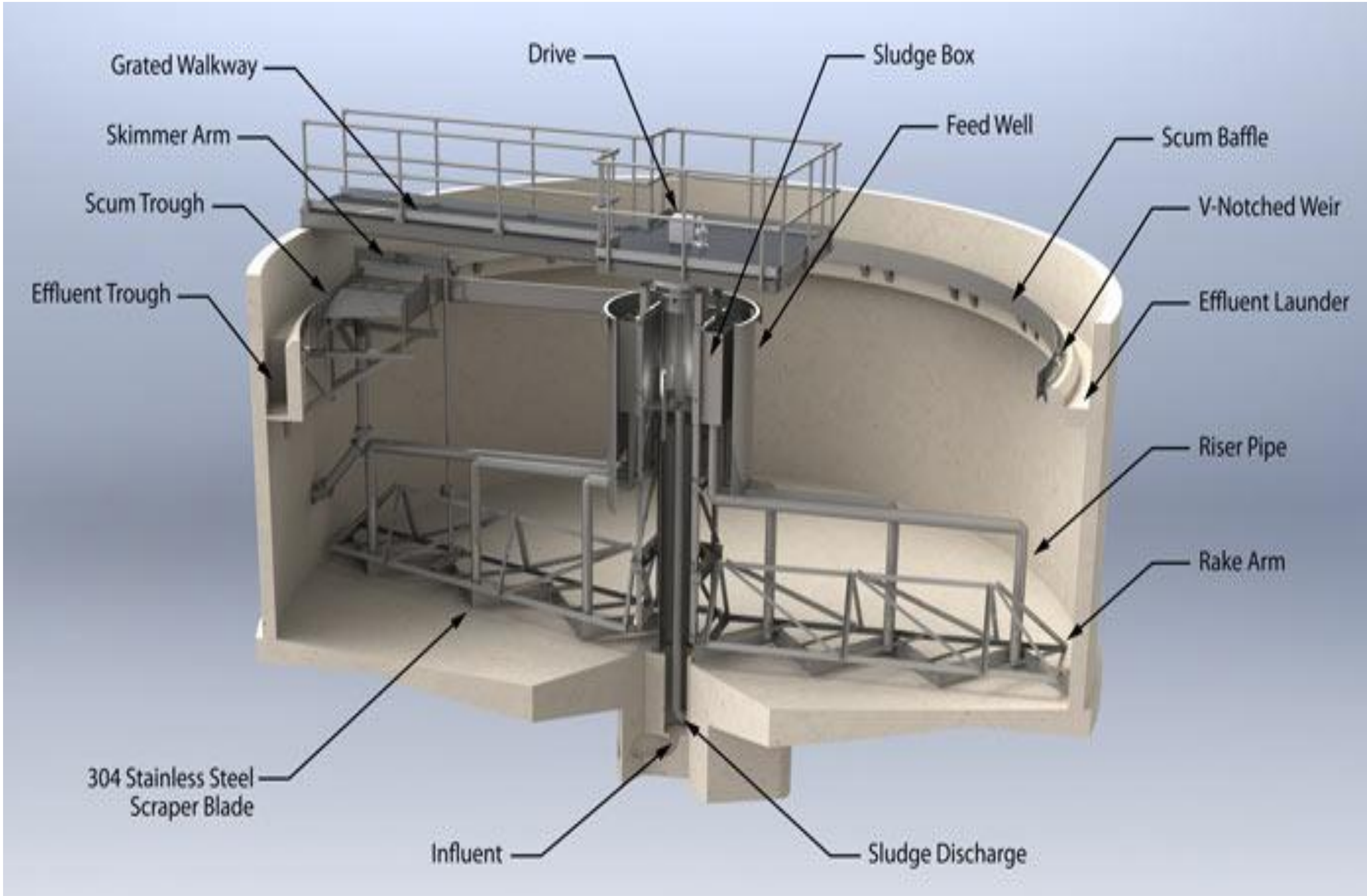
Surface:

Primary clarifier	q_A = 2 to 6 m/h
Secondary clarifier	q_A = 0.5 to 1.5 m/h

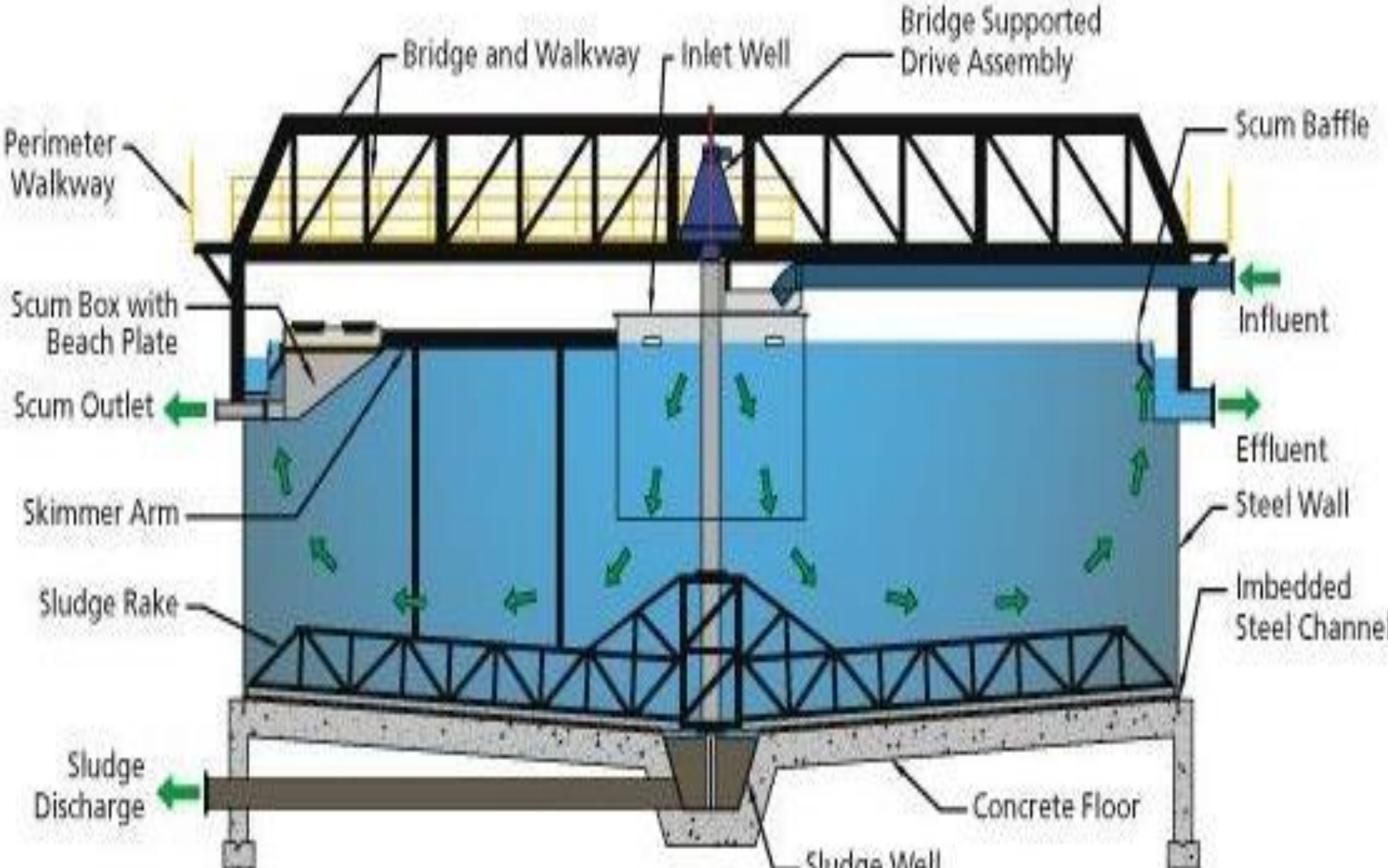
Design of Sedimentation Basins

In circular basins, the flow may enter around the perimeter, as shown in the figure below or at the center as shown in the figure below. The flow pattern is more complicated than in rectangular basins, and there is more opportunity for short circuiting.


shutterstock
IMAGE ID: 153095855
www.shutterstock.com



Grated Walkway
Drive
Sludge Box
Feed Well
Skimmer Arm
Scum Baffle
Scum Trough
V-Notched Weir
Effluent Trough
Effluent Launder
Riser Pipe
Rake Arm
304 Stainless Steel
Scraper Blade
Influent
Sludge Discharge



Bridge and Walkway
Inlet Well
Bridge Supported
Drive Assembly
Perimeter
Walkway
Scum Baffle
Influent
Scum Box with
Beach Plate
Scum Outlet
Effluent
Skimmer Arm
Steel Wall
Sludge Rake
Imbedded
Steel Channel
Sludge
Discharge
Concrete Floor
Sludge Well

Design of Sedimentation Basins

Studies of the flow pattern in circular clarifiers have indicated that the average detention time is greater in peripherally fed basins than in those in which the flow enters in the centers.

Design of Sedimentation Basins

Clean equipment in circular basins usually consists of scraper blades mounted on redial arms. The bottom of the basin is sloped toward the center hopper, and the rotating blades push the sludge into a series of windrows which are gradually worked to the center. Circular basins have smaller wall area for a given plan area but not permit common wall construction.

Design of Sedimentation Basins

Careful design of inlets and outlets is very important to the proper operation of clarifiers.The ideal inlet reduces the entrance velocity to prevent development of currents toward the outlet, distributes the water as uniformly as possible across the basin, and mixes it with water already in the tank to prevent density currents.

Design of Sedimentation Basins

Some typical designs which offer a compromise between simplicity and function are illustrated in figure below. Poorly designed inlets are the most common cause of poor clarifier performance.

Design of Sedimentation Basins

Outlets of clarifiers usually consist of weirs which skim the clarified water from the surface and are sufficiently long to reduce the local velocity in their vicinity to levels which will not resuspend solids. The design of weirs is based on a weir loading or weir overflow rate expressed in flow per unit length.

Design of Sedimentation Basins

Effluent weirs are placed as far from the inlet as possible – at the opposite end of rectangular basins, around the perimeter of center – fed circular tanks, and toward the center and along the radii of peripherally fed basins. The weirs with their associated effluent channels may cover a substaintial portion of the area of the basin. The area so covered is still an effective part of the clarifier and is not subtracted in determining the SOR.

Design of Sedimentation Basins

Typical weirs consist of 90° V notches. The length calculated from the weir overflow rate is the total length, not the length over which flow occurs.

A compilation of typical surface overflow rates, weir overflow rates, and detention times which have been used in water treatment are presented in table below.

Design of Sedimentation Basins

These values are provided for purposes of comparison, not as recommended design standards.

Design of water treatment systems should be based on laboratory evaluation of the systems which are proposed.

Design of Sedimentation Basins

Table (1):Typical water treatment clarifier design details

Type of basi	Detention time, h	Weir overflow rate, (m^3/m.day)	Surface overflow rate, (m/d)
Presedimentation	3-8		
Standard basin following:			
Coagulation and flocculation	2-8	250	**20- 33**
Softening	4-8	250	**20-40**
Upflow clarifier following:			
Coagulation and flocculation	2	175	**55**
Softening	1	350	**100**
Tube settler following:			
Coagulation and flocculation	0.2		

Example: Designing a long-rectangular settling basin for type -2 settling:

A city must treat about 15000 m3/d of water. Flocculating particles are produced by coagulation, and a column analysis indicates that an overflow rate of 20 m/d will produce satisfactory removal at a depth of 3.5 m. Determine the size of the required tank.

SOLUTION:

1- Compute surface area (provide two tanks at 7500 m3/d each)

Q= vs . As

7500 m3/d =As × 20 m/d

As =7500/2= 375 m2

2-Select a length- to-width ratio of 3/1, calculate surface dimensions:

w× 3w= 375 m2

Width=11.18 say 11 m

Length= 33.54 say 34 m

3- Check the retention time:

T=volume/flow rate=11m× 34m× 3.5m /(7500 m3/d × 1 d/24h)

=4.19 h

4-Check horizontal velocity:

Vh =Q/As =(7500 m3/d× d/24h)/11m× 3.5m = 8.1 m/h

Design of Sedimentation Basins

5-Check weir overflow rate. If simple weir is placed across end of tank, overflow length will 11 m and overflow rate would be:

$7500 m^3/d \times 1d/24h \times 1/11m = 28.4\ m^3/h.m$

Five times this length will be needed

Example:Designing a circular settling basin:

Using the data in above example, determine the diameter required for settling basins.

Solution:

1- Again providing two tanks, the surface area is calculated as before

As =375 m2

Design of Sedimentation Basins

2- The diameter is calculated by

$\pi d2/4 = 375$ m2

d=21.85 say 22 m

PRESEDIMENTATION (PLAIN SEDIMENTATION)

Presedimentation facilities (see Fig. R-1) are used to remove easily settleable sand and silt, often present in surface water supplies, especially rivers, to avoid silting in treatment plant inlet piping. In general, presedimentation basins and tanks should be located upstream of any raw-water pumping facility (low-lift pumps) and as close as possible to the intake structure to avoid silting problems in the plant intake pipeline.

Typical design criteria for presedimentation tanks are listed in Table R-1.

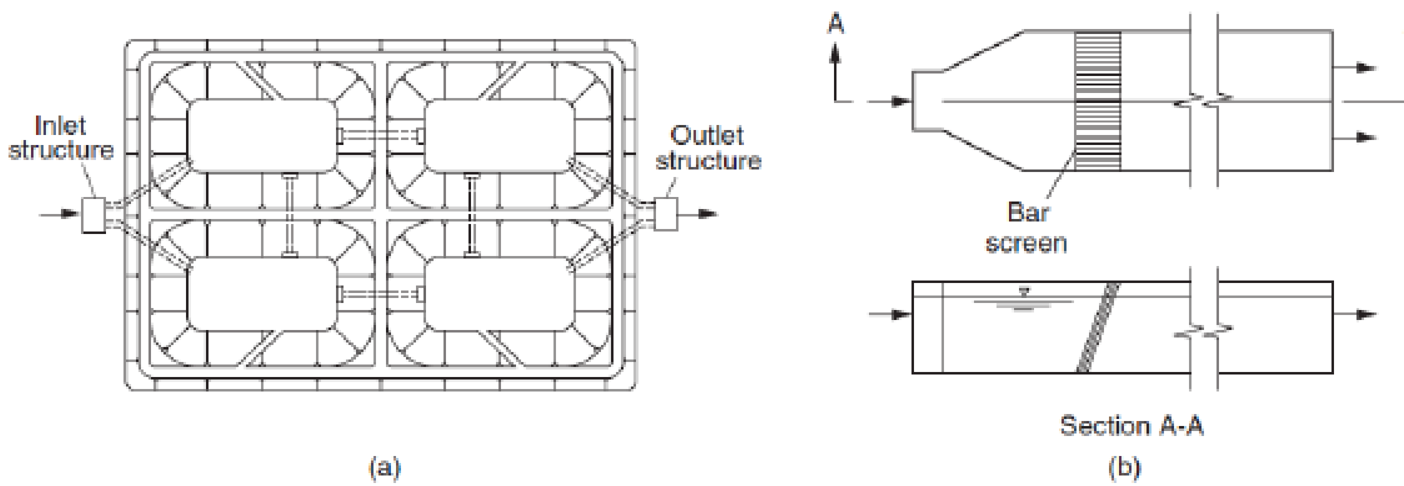


FIGURE R-1

Typical presedimentation facilities: (a) earthen basins (both lined and unlined) and (b) rectangular tank shown without continuous mechanical sediment removal facilities.

TABLE R-1

TYPICAL PRESEDIMENTATION TANK DESIGN CRITERIA

Parameter	Units	Value
Type	—	Horizontal-flow rectangular tank
Minimum number of tanks	Unitless	2
Depth (without automated sediment removal)	m	3.5 – 5
Depth (with automated sediment removal)	m	3 – 4
Minimum length-to-depth ratio	Dimensionless	6 : 1
Length-to-width ratio	Dimensionless	4 : 1 – 8 : 1
Surface loading rate	$m^3/m^2 \cdot d$	200 – 400
Horizontal mean flow velocity (at maximum daily flow)	m/s	0.05 – 0.07
Detention time	min	6 – 15

Minimum size of particle to be removed	mm	0.1
Bottom slope	m/m	Minimum 1:100 longitudinal slope

Assuming ideal settling in a rectangular basin, then:

$$v_f = \frac{L}{t}$$

$$v_s = \frac{h_o}{t}$$

$$\frac{v_f}{v_s} = \frac{\frac{L}{t}}{\frac{h_o}{t}} = \frac{L}{h_o}$$

Then , the required length of a presedimentation tank is:

$$L = \frac{v_f}{v_s} h_o \quad or \quad L = K \frac{h_o}{v_s} v_f$$

Where :

L = length, m

K = safety factor (typically 1.5 to 2), unitless

h_o or d = effective water depth, m

v_s or v_p = settling velocity of particle to be removed, m/s

v_f or v_h = mean water velocity at maximum day flow rate, m/s

EXAMPLE :

Two presedimentation tanks are designed to remove sand of 0.1 mm and larger for an average flow of 1.0 m^3/s. The maximum flow rate is to be 1.5 times the average flow and the water temperature is 10 °C. Assuming a typical water depth of 3.0 m and a factor of safety of 1.75, determine the length and width of each tank and check that the surface loading (overflow) rate and the detention time are within the recommended design criteria

ranges.

SOLUTION

- For water temperature is 10 °C, ($\nu = 1.306 \times 10^{-6}$ m^2/s) , then settling velocity of particles can be calculated as:

$$v_p = v_s = \frac{g\,(s\,g_p - 1)d^2{}_p}{18v} = \frac{9.81\frac{m}{s^2}(2.65-1)(0.0001)^2}{18\,x\,1.306\,x10^{-6}\;m^2\,/s}$$

$$= 0.0069\;m/s$$

$$The\ cross\ sectional\ area\ of\ each\ tank\ = A$$

$$= \frac{maximum\ flow}{flow\ velocity} = \frac{Q_{max}}{v_f}$$

- From Table R-1, the horizontal mean flow velocity at maximum flow is 0.05 m/s

$$A = \frac{1.5\ x\ 1.0\ m^3/s}{2\ tanks}\ x\ \frac{1}{0.05\ \frac{m}{s}} = 15\ m^2\ = Width\ x\ Depth$$

- For a water depth of $h_o = 3.0$ m, the width is :

$$Width, W = \frac{15\ m^2}{3\ m} = 5\ m$$

- Length of each tank is :

$$L\ = K\ \frac{h_o}{v_s}\ v_f = 1.75\ \left(\frac{3\ m}{0.0069\ m/s}\right)\ x\ 0.05\frac{m}{s} = 38\ m$$

- Verify the length-to-depth (L/d) and length-to-width (L/w) ratios.

$$\frac{L}{d} = \ \frac{38}{3} = \frac{12.7}{1} > \frac{6}{1} \qquad OK$$

$$\frac{L}{W} = \ \frac{38}{5} = \frac{7.6}{1} > \frac{4}{1} \qquad OK$$

- Verify the detention time and surface loading rates:

$$detention\ time for\ Q_{avr}\ .t\ = \frac{Volume}{Q}$$

$$= \frac{38\ m\ x\ 5\ m\ x\ 3\ m}{\frac{1\ m^3/s}{2\ tanks}\ \ x\ 60\ s/min} = 19\ min.$$

The calculated value is higher than the typical range of detention time given in Table R-1 (6 to 15 min) for average flow conditions.

$$detention\ time\ for\ Q_{max}\ .t\ = \frac{19\ min}{1.5} =\ 12.7\ min$$

. The detention time is within the acceptable range of (6 to 15 min).

- Determine the surface loading rate, OR:

$$OR = v_c = \frac{Q}{A} = \frac{1\frac{m^3}{s}\ x\ 3600\frac{s}{h}x\ 24\ h/d}{38\ m\ x\ 5\ m\ x\ 2\ tanks} = 227\ m^3/m^2.d$$

The surface loading rate range recommended in Table R-1 is 200 to 400 $m^3/m^2 \cdot d$. Thus, the computed value is within the acceptable range.

RECTANGULAR SEDIMENTATION BASINS

Rectangular tanks are designed with inlets at one end and outlets at the other end. The sludge hopper is provided at the inlet end of the tank. Many sedimentation basins are rectangular with horizontal flow, as shown on Fig. R-2 and Plates R-1. A minimum of two basins should be provided so that one may be taken off-line for inspection, repair, and periodic cleaning while the other basin(s) remain in operation. Basins arranged longitudinally side by side, sharing a common wall, have proven to be a cost-effective approach. In addition, a flocculation process may be incorporated into the head end of the sedimentation basin, minimizing piping, improving flow distribution to sedimentation basins, and potentially reducing floc damage during transfer between the flocculation stage and the sedimentation stage. Typical design parameters used for rectangular sedimentation facilities are summarized in Table R-2.

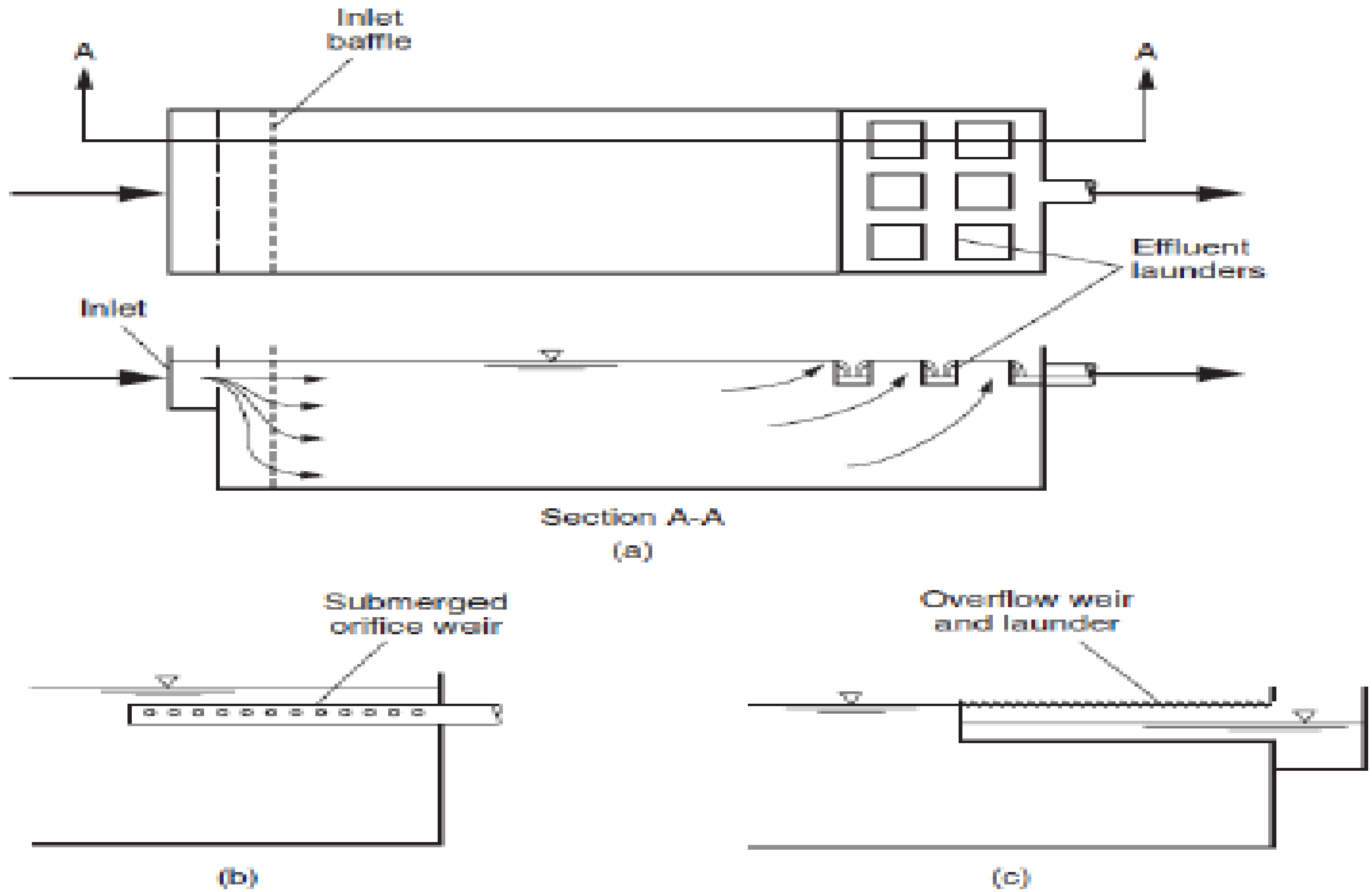


FIGURE R-2

Rectangular, horizontal-flow sedimentation basin with various outlet types:

(a) inboard effluent launders, (b) submerged orifice withdrawal, and (c) overflow weir and launder.

PLATES R-1

HORIZONTAL FLOW RECTANGULAR SEDIMENTATION BASINS

TABLE R-2

TYPICAL DESIGN CRITERIA FOR HORIZONTAL FLOW RECTANGULAR SEDIMENTATION TANKS

Parameter	Units	Value
Type	—	Horizontal-flow rectangular tank
Minimum number of tanks	Unitless	2
Water depth	m	3 – 5
Length-to-depth ratio, minimum	Dimensionless	15 : 1
Width-to-depth ratio	Dimensionless	3:1 – 6:1
Length-to-width ratio, minimum	Dimensionless	4 : 1 - 5 : 1
Surface loading rate (overflow rate)	m/h	1.25 – 2.5
Horizontal mean-flow velocity (at maximum daily flow)	m/min	0.3 – 1.1
Detention time	h	1.5 – 4
Launder weir loading	$m^3/m \cdot h$	9 – 13

Reynolds number (N_R or Re)	Dimensionless	< 20000
Froude number	Dimensionless	$> 10^{-5}$
Bottom slope for manual sludge removal systems	m/m	1 : 300
Bottom slope for mechanical sludge scraper equipment	m/m	1: 600
Sludge collector speed for collection path	m/min	0.3 – 0.9
Sludge collector speed for the return path	m/min	1.5 – 3

HORIZONTAL FLOW VELOCITY

Settling characteristics and surface loading are generally the main basis of design, with Reynolds and Froude numbers being used as a check on turbulence and back mixing. The Reynolds number is determined as:

$$N_R = \frac{v_f R_h}{\nu} = \frac{\rho v_f R_h}{\mu}$$

where

N_R = Reynolds number based on hydraulic radius, dimensionless

v_f = average horizontal fluid velocity in tank, m/s

R_h = hydraulic radius = A_x / P_w, m

A_x = cross-sectional area, m^2

P_w = wetted perimeter, m

ν = kinematic viscosity, m^2/s

μ = dynamic viscosity, (kg/m.s)

ρ = density of water, kg/m^3

The Froude number may be determined using the equation:

$$Fr = \frac{{v_f}^2}{g R_h}$$

Where

Fr = Froude number, dimensionless

g = acceleration due to gravity, 9.81 m/s^2

EXAMPLE:

Two rectangular settling tanks are each 6 m wide, 24 m long, and 2.1 m deep. Each is used alternately to treat 1900 m^3 in a 12 h period. Compute the surface overflow (settling) rate, detention time, horizontal velocity, and outlet weir loading rate using V-shaped weir with three times the width.

Solution:

Determine the design flow Q:

$$Q = \frac{1900\ \mathrm{m^3}}{12\ \mathrm{h}} \times \frac{24\ \mathrm{h}}{1\ \mathrm{d}}$$
$$= 3800\ \mathrm{m^3/d}$$

Compute surface overflow rate SOR:

$$\mathrm{SOR} = Q/A = 3800\ \mathrm{m^3/d} \div (6\ \mathrm{m} \times 24\ \mathrm{m})$$
$$= 26.4\ \mathrm{m^3/(m^2 \cdot d)}$$

Compute detention time t:

$$\text{Tank volume } V = 6\ \mathrm{m} \times 24\ \mathrm{m} \times 2.1\ \mathrm{m} \times 2$$
$$= 604.8\ \mathrm{m^3}$$
$$t = V/Q = 604.8\ \mathrm{m^3}/(3800\ \mathrm{m^3/d})$$
$$= 0.159\ \mathrm{d}$$
$$= 3.8\ \mathrm{h}$$

Compute horizontal velocity v_h

$$v_h = \frac{3800\ \text{m}^3/\text{d}}{6\ \text{m} \times 2.1\ \text{m}}$$
$$= 301\ \text{m/d}$$
$$= 0.209\ \text{m/min}$$

Compute outlet weir loading rate, WOR:

$$\text{WOR} = \frac{3800\ \text{m}^3/\text{d}}{6\ \text{m} \times 3}$$
$$= 211\ \text{m}^3/(\text{d} \cdot \text{m})$$

EXAMPLE

A water treatment plant that is used to produce 100000 m^3/d drinking water is designed to remove grit and sand from a river water with a diameter of 0.02 , mm, and density, $\rho_p = 2650\ kg/m^3$. Water is at 20 °C. Design :

1- rectangular sedimentation tanks

2- Circular sedimentation tanks

SOLUTION

For water at 20 °C : (Table S-1)

$\mu = 1.002x10^{-3}\ N.s/m^2$ at 20 °C

$\rho_w = 998.2\ kg/m^3$

Find the settling velocity (v_c) for sand particles. Assume first the flow is laminar and check for Reynolds number:

$$v_c\,(SOR) = \frac{g\,(\rho_p - \rho_w)d^2{}_p}{18\mu}$$

$$v_c\,(SOR) = \frac{(9.81\ m/s^2)(2650 - 998.2)(0.02\ x\ 10^{-3}\ m)^2}{18\,(1.002\ x\ 10^{-3}\ N.s/m^2)}$$

$$= 3.59\ x\ 10^{-4}\ m/s$$

$$N_R = \frac{v_p\, d_p\, \rho_w}{\mu}$$

$$= \frac{\left(3.59\ x\,10^{-4}\,\frac{m}{s}\right)(0.02\ x\,10^{-3}\ m)(998.2\ kg/m^3)}{(1.002\ x\,10^{-3}\ N.s/m^2)}$$

$$= 0.00715$$

$$N_R < 1 : so\ its\ laminar\ flow$$

Hence ,

$$v_c\,(SOR) = 3.59\ x\,10^{-4}\,m/s = 31m/d$$

<u>**Design rectangular sedimentation tanks:**</u> **use four tanks**

$$A = \frac{Q/4}{SOR} = \frac{\frac{100000}{4}\ m^3/d}{31m/d} = 806.45\ m^2$$

Select length to width ratio $\frac{L}{W} = 5{:}1$

A = W x L = W x 5W = 806.45 m^2

W= 12.7 m , L = 63.5 m

Assume detention time = 3 hrs,

$$v_c\,(SOR) = \frac{depth}{detention\ time}$$

$$depth, h = detention\ time\ x\ \ v_c = \frac{(3\ hrs\ x\ 31m/d)}{24\ h/d}$$

$$= 3.88\ m = 3.9\ m\ (ok)$$

Check:

$$\frac{L}{h} = \frac{63.5}{3.9} = \frac{16.28}{1}$$

The basin length-to-depth ratio is 16.28 : 1, which is greater than the minimum recommendation of 15:1.

$$\frac{W}{h} = \frac{12.7}{3.9} = \frac{3.25}{1}$$

The basin width -to-depth ratio is 3.25:1, which is within the recommendation of 3:1 to 6:1.

$$v_h\,(horizontal\ velocity) = \frac{Q}{W\ x\ h}$$

$$= \frac{(100000\ m^3/d)\ /4}{12.7\ m\ x\ 3.9\ m\ x\ 24\frac{h}{d}\ x\ 60\ min/h}$$

$$= \ 0.35\ m/min$$

The mean velocity is greater than 0.3 m/min and less than 1.1 m/min.

Check the Reynolds and Froude numbers

$$N_R = \frac{\rho v_f\, R_h}{\mu}$$

$$R_h = \frac{A_X}{P_W} = \frac{3.9\, m\, x\, 12.7\, m}{12.7\, m + 2(3.9\, m\,)} = 2.42\, m$$

$$v_f = \frac{0.35\, m/min}{60\, s/min} = 0.0058\, m/s$$

$$N_R = \frac{\rho v_f\, R_h}{\mu} = \frac{998.2\, \frac{kg}{m^3}\, x\, 0.0058 \frac{m}{s} x\, 2.42\, m}{1.002\, x\, 10^{-3}\, N.\frac{s}{m^2}} = 13983$$

$$< 20000$$

The Reynolds number of 13983 is less than the recommended value of 20000 for a horizontal sedimentation basin.(Ok)

The Froude number is given by:

$$Fr = \frac{{v_f}^2}{gR_h} = \frac{(0.0058\, m/s)^2}{9.81 \frac{m}{s^2}\, x\, 2.42\, m} = 1.417\, x\, 10^{-6}$$

$$= 1.411\, x\, 10^{-6} < 10^{-5}$$

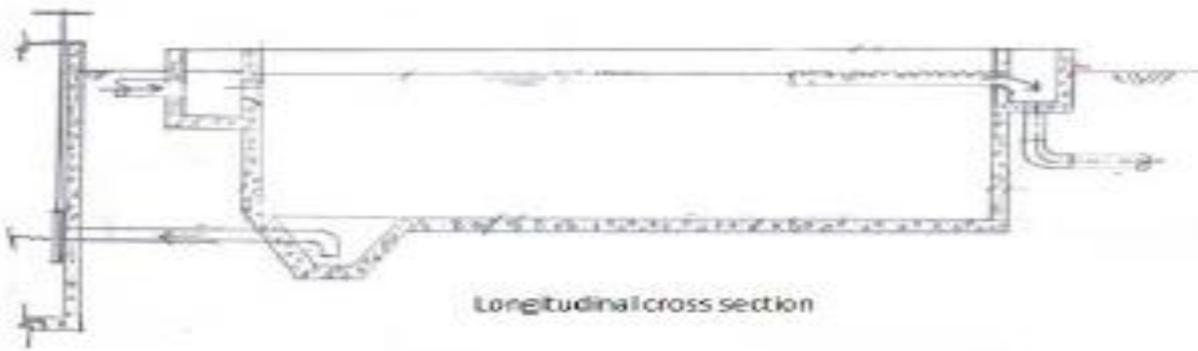
The Froude number is lower than the recommended value for sedimentation tanks, so the tank design must be modified. (Not Ok)

Take weir over flow rate (WOR) of 13 $m^3/m^2.h$ = 312 $m^3/m^2.d$:

$$\boldsymbol{length\ of\ weir = \frac{Q}{WOR} = \frac{(100000\frac{m^3}{d})/4}{312\ m^3/m.d} = 80\ m}$$

$$\boldsymbol{> width\ of\ the\ tank}$$

Hence : use suspended troughs inside the tank



Longitudinal cross section

Plan

TABLE R-3

TYPICAL DESIGN CRITERIA FOR CIRCULAR SEDIMENTATION TANKS

Parameter	Units	Value
Type	—	Radial-flow cirular tank
Minimum number of tanks	Unitless	2
Side water depth	m	2 – 6
Surface loading rate (overflow rate)	$m^3/ m^2.d$	20 – 60
Detention time	h	1 – 3
Weir loading	$m^3/m \cdot d$	170 - 350
Diameter	m	3-60
Bottom Slope		1/16 – 1/6
Flight Speed	r/min	0.02-0.05

PLATES R-2

CIRCULAR SEDIMENTATION BASINS